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Keywords: Firms, innovativeness, international, measurement

JEL classification: O32

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DEFINING AND MEASURING THE INNOVATIVENESS OF FIRMS

1. Introduction

The main objective of this paper is to operationalise an encompassing measure of the innovativeness of the firm proposed in existing literature, and to calculate estimates of that measure enabling comparisons primarily across countries, industries, and time. Publicly available international firm level accounting data is used for this purpose. The main concern of the paper is comparison rather than explanation of performance, and the use of 'residual' techniques might lead one to consider that the exercise falls broadly within the realms of growth accounting (Hulten, 2010). The emphasis upon the firm level enables much insight over and above that which can be gained from country or industry level measures which tend to report only the estimate of the mean of any chosen indicator. Firm level data enables one to generate indicators of the whole distribution of performance across firms and thus in addition to illustrating inter-firm heterogeneity, enables the calculation of the standard error of estimates by which the significance of differences between means may be compared.

The definition of innovation employed in this paper is that innovation is "the successful exploitation of new ideas". This definition has been at the centre of much of the policy debate in the UK surrounding innovation and support for innovation[1] and has close parallels to the work of Roper, Du and Love (2008) on the Innovation Value Chain (IVC) initially proposed by Hansen and Birkinshaw (2007), encompassing firm activities relating to the sourcing,

[1] This definition is often associated with the Innovation Unit of the Department for Business, Innovation and Skills (DBIS, formerly the Department for Trade and Industry, DTI, and now the Department for Business, Energy and Industrial Strategy, DBEIS). The definition appears in 2007 (see http://webarchive.nationalarchives.gov.uk/20070102021705/http://www.dti.gov.uk/innovation/) and has also featured extensively in its policy documents, see for example DBERR (2008), p. 18.

transformation and exploitation of knowledge[2]. With its emphasis upon success, this definition of innovation stresses the outputs from innovative activity and emphasises that investment in innovation activities is of little economic relevance unless it generates "success". It also has two other advantages in that: (i) it is not restricted to the scientific, technological or functional and as such has the potential to both cover a wide area of innovative activity including soft innovation (see Stoneman, 2010) and a wide range of innovations (Battisti and Stoneman, 2010) including organisational, managerial and marketing innovations; (ii) it brings one closer to more recent definitions of innovations that are designed to reflect the contributions of investment in knowledge (or intangible) capital (see Clayton et. al., 2009, and Haskel and Westlake, 2017).

This measure of innovation differs from that offered by the Oslo manual (see OECD/Eurostat, 2018, for the latest, fourth, edition) and widely used in much of the current innovation literature, for example, the Community Innovation Survey[3]. These dominant guidelines define (business) innovation as

"*A business innovation is a new or improved product or business process (or combination thereof) that differs significantly from the firm's previous products or business processes and that has been introduced on the market or brought into use by the firm*" (OECD/Eurostat, 2018, p. 20).

[2] Hansen and Birkinshaw (2007) first introduced the three steps of the innovation value chain, namely idea generation (knowledge sourcing), conversion (knowledge transformation) and diffusion (exploitation).

[3] The Community Innovation Survey is the main source of firm level innovation statistics and is carried out by EU member states and a number of ESS member countries. In the UK the survey is carried out by the Office for National Statistics on behalf of the UK department of Business, Energy and Industry Strategy and contains information on about 15,000 UK firms operating in the various sectors of the economy.

where business processes encompass the production and delivery of products for sale, and marketing and organisational innovations (OECD, 2018, p. 21), and both products and processes are considered as new if they are new to the firm (rather than to the market or to the world). The guidelines also make it clear that:

(i) The minimum requirement for an activity to be an innovation is that the new product or business process must have one or more characteristics that are significantly different from those contained in the products previously offered or the business processes previously used by the firm. In the latest Oslo manual definitions the past emphasis on technological characteristics has been modified, and now relevant characteristics can also include non-technological (e.g. appearance) and non-functional characteristics such as affordability and financial convenience. Although the concept of a "significant" difference excludes minor changes or enhancements the definitions do not offer a definition of what is significant.

(ii) To the economist, significance might well be judged by market impact. However the Oslo manual definitions do not require an innovation to be a commercial, financial or strategic success (at the time of measurement or ever). Under these definitions a product innovation can fail commercially or a business process innovation may require more time to meet its objectives and still be considered to be significant. In a world where failure rates of the order of 40% in product innovation seem to be indicated in the literature (Castellion and Markham, 2013) this indicates a problem with the definition. Basically, the OECD definition of innovation stresses innovation activity rather than the output of that activity or the impact of that activity upon economic performance. Essentially this is rather like saying that when judging a football game, it should not be goals actually scored that matter, but shots on goal (however wide of the mark) that should count. In this paper, on the contrary, we consider a firm to be innovative only if its innovative activity improves firm performance.

The innovation concept employed in this paper i.e. the successful exploitation of new ideas, has two main elements, exploitation and success. We here consider that each firm has access to a stock of knowledge made up of ideas developed over time (inside or outside the firm) and which at any moment in time it may employ in its product offerings or production and business processes. Such employment or usage here represents their exploitation. Our approach proceeds on the basis that the exploitation of all ideas new to the firm represent innovative activity (but not innovation per se which also requires success), whether those ideas are original and new to the world, or already employed elsewhere but new to the market, or already used in the market and only new to the firm (the same as in the Oslo manual). However, firms often take time (sometimes a considerable period of time) to completely change technologies (often known as the intra firm diffusion process, see Stoneman, 2002) or to adopt innovative practices, and the later stages of this process represent innovation by the firms as much as do the early stages. We thus consider that the exploitation of new ideas concerns both the first use by a firm of ideas that it has not used before, and also the more extensive use at a point in time of new ideas it has used before.

The second element of the definition is "success". This may be differently defined according to context[4]. In this paper, as we are primarily interested in the corporate or firm level and are thus concerned with defining and measuring the impact of exploiting new ideas on firm level

[4] In a macro context the definition may encompass increases in economic welfare in general. In fact between 2003 and 2011 the DBIS definition was extended to read: "Innovation is the process by which new ideas are successfully exploited to create economic, social and environmental value" (http://www.bis.gov.uk/innovation). It might also be the case that if one were interested in, for example, knowledge creation per se then one might even define success by the extent of additions to the knowledge stock.

success, the obvious measure of success to employ at the corporate level is the impact upon profit (an area previously addressed in the literature by, for example, Geroski et. al. 1993, and Leiponen, 2000[5]). Profitability may be viewed at a point in time or from an inter-temporal viewpoint when it will be reflected in the market value of the firm. It is often argued that, as a residual, profits per se at a point in time are too random to be an effective measure of firm performance and are thus not an ideal indicator to use, whereas market value measures of profitability may remove such year to year volatility. There is a literature (e.g. Hall, 1993, 1998, Hall et. al., 2005 and Toivanen et al., 2002) that explores the impact of innovation, measured by, for example, R&D and patenting, on the market value of the firm. However it is not clear whether market values reflect current innovation as opposed to expected future innovation activities. Moreover current profit measures have the advantage of being much more closely linked to measures deriving from the literature on growth accounting and the growth of total factor productivity which we consider to be an advantage. We thus employ current profit as the indicator of profitability.

Reflecting these two arguments, in the sections below we generate an all encompassing measure of the innovativeness of the firm by deriving a measure of the contribution to the firm's profit growth at each point in time from the first, or more intensive, deployment within the firm at that time of products, processes, materials, management and marketing methods new to that firm. Using this measure, the most innovative firm need not be that with the most up to date products and business processes, rather it could be a firm that has changed its products and processes from what they were, although not to the most up to date, but by so doing has generated the largest increase in its profits.

[5] Although one may note that very little of the literature relating profitability to innovation provides any theoretical underpinnings to the empirical work presented. Here we provide such an underpinning to our work.

The measure of firm innovativeness employed is all encompassing in terms of innovation activities. To date very few studies of firm level innovative activity have been so encompassing, despite the inclusiveness of the Oslo definitions. In fact most firm level studies use single indicator proxies that are assumed to indicate innovativeness[6]. For example, in the UK, the Department for Business Innovation and Skills has published firm level data upon R&D (as well as value added and CAPEX) in various scoreboard reports (see for example DTI, 2005) although no longer continued. There are also R&D scoreboards in several other countries, e.g. the US, Netherlands, Finland, and Australia as well as for Europe as a whole (see European Commission, 2017). But R&D is a measure of input, and only one input of many at that, to the innovative process and cannot therefore alone be a good measure of innovative activity, and it is especially unlikely to be at all appropriate for many service industries where innovative activities do not take place in formalised R&D labs (Battisti et al, 2014). Similarly a commonly cited indicator based on Community Innovation Survey data is the proportion of firms' sales that derive from recently or newly launched products. This however is a measure of product innovation and does not reflect process innovation and thus, standing alone, cannot be a good overall indicator. A third widely used indicator is counts of patents granted to the firm (or counts of other Intellectual Property grants), but such counts have many problems as a measure (as has been well known for some time, see Griliches, 1990) for example, patents vary in quality (a problem that can, however, be tackled), different industries have different propensities to patent, and some advances (e.g. in software) cannot be patented. Overall, in our view, currently, we do not have

[6] Although Bosworth et. al. (1994) in a report for the Department for Trade and Industry explored the feasibility of defining and measuring an all encompassing firm level innovation indicator, the method proposed at that time was not considered suitable for need and the report has not been released in to the public domain. Battisti, Mourani and Stoneman (2010) also considered the construction of an encompassing firm level measure of innovativeness but that paper is not only confined to analysis of the UK, but has several other failings that make it unreliable.

adequate measures of firm level innovativeness in that: (i) the OECD definitions upon which many current studies are based are flawed and in particular fail to take account of the argument that innovative activities are only to be valued if they improve firm performance: (ii) there is a dearth of studies that employ encompassing measures[7]; and (iii) there are in any case very few national or international studies at the firm level.

The rest of this paper is structured as follows. Section 2 formalises the concepts employed, introduces the main modelling constructs, and derives the indicator of firm level innovativeness. Section 3 discusses measurement and data sample characteristics, section 4 presents the overall patterns in the estimates and section 5 undertakes univariate analyses by country, sector and time. Section 6 considers multivariate analysis and section 7 considers causality issues. The final section concludes.

2. Formalising concepts and the derivation of a measure of the successful exploitation of new ideas

2.1 Introduction

In this section we first discuss the measure of profit to employ which then leads naturally to a specification for modelling demand for the firm's output. We then model production and

[7] One reaction to the unsuitability of single proxies is to produce multivariate balanced scorecards. For example, the European Commission generate a European Innovation Scoreboard, the latest results published as European Commission (2018), (see https://ec.europa.eu/growth/industry/innovation/facts-figures/scoreboards_en). A composite summary Innovation Index is calculated for each country as the unweighted average of the scores for 27 different innovation input and output indicators with all indicators receiving the same weight (1/27 if data are available for all 27 indicators). This weighting scheme seems arbitrary. In any case this is undertaken not at the firm level but at the economy wide level.

discuss the representation of the exploitation of new ideas by the firm. This is followed by derivation of the measure of the innovativeness of the firm.

2.2 Defining Profits

There are two potential indicators of current profits that can be employed. The first is operating profits, which for firm i in time t we write as S(i,t); the second is net profits which we write as Π(I,t). S(i,t) is equivalent to earnings before interest, taxes, debt repayments and amortisation (ebitda). Π(I,t) is essentially equal to S(i,t) less the cost of capital (which may be considered to be normal profits) and thus may also be considered to be excess profits .

The profit maximising firm will act to maximise excess or net profits, Π(I,t), and it is the impact of innovation on Π(I,t) that is of most interest. However, as shown in standard text books, under perfect competition, with constant returns to scale, a profit maximising, price taking firm employing factors to the point which equalises their price and marginal products exhausts value added and earns no excess profits (only normal profits being earned). Thus if perfect competition prevailed permanently, innovation would not generate any excess or net profits, Π(I,t). To overcome this reasoning, one may argue in a Schumpeterian way (Schumpeter, 1911) that innovation by a firm creates a temporary divergence from a perfectly competitive steady state, such that, from an initial position where only normal profits are earned, innovation temporarily leads to an increase in the firm's excess profits above zero which are then competed away over time, through emulation, until only normal profits again are being earned. Alternatively, rather than such a temporary gain in market power, one may argue that firms earn excess profits because the markets in which they operate are permanently imperfect, and as such they do not permanently have zero excess profits. In this paper we take the second approach.

Although we would like to be able to concentrate upon the impact of the use of new ideas on excess profits we are unable to estimate the cost of capital or normal profits, given the various sources of finance for any firm and the related costs e.g. interest payments, dividends etc. and thus we proceed by analysing the determinants of changes over time in S(i,t), operating profits, which we are able to measure. In particular, defining P(i,t) as the price of the output of firm i in time t, and Y(i,t) as its level of output in time t, P(i,t)Y(i,t) may be considered to be either total revenue of the firm or (synonymously in the current context where intermediate inputs are netted out) the gross nominal value added of the firm, V(i,t). By definition, if W(i,t) is the wage per unit of human capital employed, and H(i,t) is the total, human capital employed, then gross nominal value added will equal operating profits plus total wages (V(i,t) = S(i,t) + W(i,t)H(i,t)). We may then write that operating profits are given by (1)

$$(1) \qquad S(i,t) = V(i,t) - W(i,t)H(i,t).$$

From (1) it is clear that firm operating profits will change over time as V(i,t) (i.e. P(i,t) and Y(i,t)), W(i,t) and H(i,t) change over time. Our intent is to separate out that part of this change that is the result of innovation. More specifically we attempt to measure the impact of innovation upon the growth of operating profits.

2.3 Modelling demand

In order to model the imperfectly competitive product markets argued above to be appropriate, we allow (as in Hall, 2011) that each firm i produces differentiated products (goods or services) and faces a downward sloping demand curve for its products, (2),

$$(2) \qquad P(i,t) = C(i,t)Y(i,t)^{(1/\eta(i))}$$

where $\eta(i)$ is the (negative of the) demand elasticity for the firm, which we assume to be constant over time[8], and C(i,t) is a shifter that represents the impact of changes (exogenous to the firm) in the general price level and demand shifts in the market in which the firm sells its output (and is thus considered market or industry, rather than firm, specific). Although C(i,t) is exogenously determined, Y(i,t) is endogenous and thus P(i,t) is also endogenous.

2.4 Modelling production and the exploitation of new ideas

To explore the impact of the exploitation of new ideas on firm performance we allow that there are two routes by which knowledge or ideas are incorporated in to the firm's production process. The first route is most relevant to new ideas relating to, for example, product innovation including new product design, or changes in organisational structure, management methods, and marketing methods which may occur without the purchase of new capital equipment and as such may be considered disembodied innovation. Sometimes known as "manna from heaven", this is the most basic and most commonly employed way in which technological change is represented in growth accounting, usually being modelled by a term

[8] Although one could argue that in a more complex world the demand elasticity might change as the firm launched sales increasing new products and/or increased market share through innovation generated lower relative prices.

in the firm's production function that, over time, enables greater output to be produced from given capital and labour inputs and which we here write as A(i,t).

The second route involves the firm in the acquisition of new (types of) capital goods that embody new ideas, primarily representing process innovation. This might, for example, encompass the purchase of new capital equipment such as stand-alone machinery, new production lines, new testing equipment or new software. This is labelled embodied innovation. Modelling the contribution of embodied innovation to firm performance is more involved than modelling disembodied innovation. Generally when there is investment incorporating new processes the contribution of that investment to the exploitation of ideas cannot be separated from the gross (and net, after scrapping) contribution to the creation of capacity (either changing the capital labour ratio or increasing the amount that can be produced). Generally one cannot introduce embodied technology without affecting capacity and one cannot increase capacity without introducing new technologies. Similarly, although innovation surveys (such as the CIS surveys) may ask "did you introduce new process technologies" and get yes or no answers, generally such approaches cannot say whether the innovation was incidental to a desired increase in capacity or was in fact the driving force behind the acquisition of new capital goods (Stoneman and Kwon, 1998).

Such embodied innovation is of course the remit of vintage models (a classic reference here being Solow, 1960) in which capital equipments of different ages produces the same final good but embody or incorporate the ideas in existence at their date of installation and as such have different productivity. Since the seminal paper by Solow there has been extensive advancement in the study of such vintage models. A useful reference is Boucekkine et al. (2011). Such vintage approaches to the related field of growth accounting have been surveyed in Hulten (2001, 2010). Here we revert to the model proposed by Solow (1960) because it is simple analytically and has some useful properties, whereas the perhaps more realistic character of a number of the later models would increase complexity but be of limited relevance in terms of the exercise performed here and the data available to us. In particular later models address two problematic characteristics of earlier vintage models. The first is that the labour force may also have vintage characteristics. Our data does not allow us to pursue this route. The second is that capital goods installed at time t may in reality embody the latest technology only with a lag. However, because we here define exploitation as involving the use of ideas new to the firm and not necessarily new to the world, this is of much less importance in the model analysed here.

Following the approach to modelling as suggested by Solow (1960), we define gross investment by firm i in time τ (and thus in capital goods of vintage τ) as $I(i,\tau)$. Reflecting the advance of process technology, we allow that the output producing capability of a unit of investment increases with the date of installation such that later vintages are more productive than earlier vintages. Specifically, defining $H(i,\tau,t)$ as labour employed in firm i on vintage τ capital in time t, then the output produced by firm i in time t on capital goods of vintage τ, $Y(i,\tau\ t)$ is assumed given by the Cobb-Douglas technology (3)

$$(3) \qquad Y(i,\tau,t) = A(i,t)[B(i,\tau).I(i,\tau)]^{\alpha(i)}\ H(i,\tau,t)^{\gamma(i)}$$

where $B(i,\tau)$ reflects the increasing productivity of capital goods over the vintages, $\alpha(i)$ and $\gamma(i)$ are parameters of the production relationship (assumed invariant to τ) and $A(i,t)$ is the term that reflects disembodied innovation as discussed above.

The (endogenous) scrapping issue is resolved in this framework by arguing that over time no capital goods are scrapped but labour is reallocated from the oldest to the newest technologies and the amount of labour allocated to each vintage is determined such that the marginal productivity of labour is equalised across vintages. As this happens so less and less is being produced on the oldest vintages. Defining Y(i,t) as the sum of Y(i,τ,t) over τ, i.e. total output in firm i at time t, H(i,t) as the sum of H(i,τ,t) over τ, i.e. total employment in firm i at time t, and Z(i,t) as the sum of B(i,τ).I(i,τ) over τ in firm i at time t, we may then write (4).

$$(4) \qquad Y(i,t) = A(i,t).Z(i,t)^{\alpha(i)}.H(i,t)^{\gamma(i)}$$

where Z(i,t) is given by (5)

$$(5) \qquad Z(i,t) = B(i,t).I(i,t) + B(i,t-1).I(i,t-1) + B(i,t-2).I(i,t-2)+\ldots\ldots\ldots B(i,t-\infty).I(i,t-\infty).$$

Thus Z(i,t) is a weighted sum of the technological capabilities of the entire firm's capital stock, where the weights are the amount of each vintage installed. Given that the rate of growth of Z(i,t), written as z(i,t), equals B(i,t).I(i,t)/Z(i,t-1), we may interpret z(i,t) as the rate of growth in time t of the technological (process) capabilities of capital installed in firm i at time t, or alternatively the rate of growth in time t of the technological capabilities of the stock of new ideas embodied in the capital stock of firm i.

2.5 Deriving the measure of the successful exploitation of new ideas

From (1), (2) and (4) it is clear that the firm's use of new ideas will impact upon profits over time both directly through the increase in output induced by A(i,t) and B(i,t) but also indirectly through changes in P(i,t) brought about by any increase in its supply of output on to the market. We assume that firms operate on competitive labour markets with W(i,t) determined exogenously to the firm and independent of innovativeness (in time t). The firm is assumed to determine its labour input to maximise net profits, Π(I,t) which yields (6) as the familiar condition that the firm employs labour to the point where its marginal value product equals the money wage.

(6) $W(i,t)H(i,t)/V(i,t) = \gamma(i)(1+\eta(i))/\eta(i)$.

Defining the share of labour in value added, $W(i,t)H(i,t)/V(i,t) \equiv 1- \beta(i, t)$ (and thus the non-labour share, $S(i,t)/V(i,t) \equiv \beta(i, t)$), from (6) it is clear that $\beta(i,t)$ is a constant over time (a characteristic also of most studies of the growth of total factor productivity, GTFP), which we write as β(i), and thus (7) holds

(7) $1 - \beta(i) = \gamma(i)(1+\eta(i))/\eta(i)$.

Writing the growth rate of a variable over time using lower case letters throughout, from (1) using (7) we derive that the growth of S(i,t) over time is given by

(8) $s(i,t) = v(i,t)$

and, given that by definition, $W(i,t)H(i,t)/V(i,t) \equiv 1- \beta(i)$, we may also state that $h(i,t) = v(i,t) - w(i,t)$ and from (8) that $h(i,t) = s(i,t) - w(i,t)$.

From the definition that $V(i,t) = P(i,t)Y(i,t)$, we may derive from (2) that

$V(i,t) = C(i, t)Y(i,t)^{(1 + 1/\eta(i))}$ which yields that

(9) $v(i,t) = c(i, t) + y(i,t)(1+\eta(i))/\eta(i)$

which after substitution from (7) and (8) yields (10)

(10) $s(i,t) = c(i,t) + y(i,t)(1 - \beta(i))/\gamma(i).$

From (4) we may derive that (11) holds

(11) $y(i,t) = a(i,t) + \alpha(i)z(i,t) + \gamma(i)h(i,t)$

which after substitution in (10) yields (12)

(12) $s(i,t) = c(i,t) + (a(i,t) + \alpha(i)z(i,t) + \gamma(i)h(i,t))(1 - \beta(i))/\gamma(i).$

Substituting into (12) for h(i,t) given that h(i,t) = s(i,t) – w(i,t) we generate (13)

(13) $s(i,t) = c(i,t)/\beta(i) - w(i,t)(1 - \beta(i))/\beta(i) + (a(i,t) + \alpha(i)z(i,t))(1 - \beta(i))/\beta(i)\gamma(i)).$

Equation (13) indicates that the growth rate of nominal operating profits over time is driven by four terms. The first two terms represent respectively (i) the positive impact of exogenous demand shifts in the market for the firms output, c(i,t), and (ii) the negative impact of exogenous growth in nominal wages, w(i,t) . The other two terms are the ones in which we are especially interested. The first encompasses the impact of growth in the utilisation of disembodied knowledge, a(i,t). Given that z(i,t) is the rate of growth in time t of the technological capabilities of the stock of new ideas embodied in the capital stock of firm i, the last term represents the impact of growth in the exploitation of new ideas embodied in the firm's capital stock. Jointly these latter two terms measure the contribution to firm profit growth of the exploitation of new ideas.

In order to measure that part of the right hand side of (13) that reflects growth in the successful exploitation of new ideas, we define the indicator M(i,t), given by (14)

$$(14) \quad M(i,t) \equiv ((a(i,t) + \alpha(i)z(i,t)).(1 - \beta(i))/\beta(i)\gamma(i))$$

and M(i,t) may be seen to equal to the growth in profits that derive from increased embodied and disembodied exploitation of new ideas. One may see from (13) that M(i,t) can be measured as a residual equal to the difference between the growth in the nominal profits of the firm and the impact upon that growth of changes in exogenously determined wage rates and demand shifts in the market for the firm's output as in (15).

$$(15) \quad M(i,t) = s(i,t) - c(i,t)/\beta(i) + w(i,t)(1 - \beta(i))/\beta(i).$$

M(i,t) as defined in (15) is the measure that we propose of the successful exploitation of new ideas. As is clear, in one number, M(i,t) measures the overall innovativeness of the firm at a point in time and therefore offers the encompassing measure that we fail to find in the existing literatures as discussed above.

It is worth noting that this measure is of a short term character. For example, it has been constructed on the assumption that the firm's innovative activity innovation does not affect the growth of the wages it pays. In fact, over time, some of any extra profits earned from innovation may be used to increase payments to labour. In addition it may be that, in the absence of blockaded entry, new firms enter an industry introducing innovations and as they do so producer prices will fall, a process that may in fact be reflected in C(i,t), or factor prices may increase, and, in a Schumpeterian way, profits may be competed away. The measure may thus best be considered as relating to the shorter term and not the longer term.

It is also worth noting that M(i,t) may be positive or negative. A negative value would (arithmetically) result if the firm's rate of profit growth were less than that which might be expected from (autonomous) shifts in demand or reductions in wages. With innovation defined as the successful exploitation of new ideas, a zero estimate implies no innovation and a negative estimate can be interpreted as negative innovation or retrogression. A zero estimate indicates that the firm does not exploit new ideas or that its exploitation does not impact upon profits. One might note that in the UK, for example, in 2015, only 18.4% of firms product innovated, with 11.9% of firms process innovating (DBEIS, 2016), which, even with the possibility of organisational and marketing innovation, allows many zero observations (Battisti and Stoneman, 2010, argue that in the 2004 CIS, 57% of the sample firms show very little innovation). A negative estimate of the innovation measure would suggest that the firm is not successful in its exploitation of new ideas. Although we have no data on process innovation failure rates, Castellion and Markham (2013), in reviewing the literature on product innovation failure rates, argue that the new product failure rate is around 40%, which although less than the commonly asserted figure of 80 - 90%, is still sufficient to indicate much unsuccessful innovation and thus the possibility of many negative values for our innovation measure.

The approach we are taking, although rather different from, is of a similar nature in its residual approach to that used in much of the literature on the measurement of the Growth of Total Factor Productivity (GTFP) where one may find discussed many of the problems associated with this approach (see, for example, Hulten, 2001, Mairesse and Mohnen, 1994 and Nordhaus, 2004). It is for example clear from the literature that any residual might reflect, in addition to innovation, inter alia, the degree of returns to scale, other drivers of changes in productive efficiency, mismeasurement of variables, and further potential endogeneity of inputs. However, any such problems are countered by that fact that the measure suggested is (i) calculable using data that is widely available in the public domain usually in a firm's published account, and (ii) offers transparency and simplicity of calculation.

2.6 The growth rate of TFP

We have derived above that in the model here, the nominal profit share in value added, $S(i,t)/p(i,t)Y(i,t) \equiv \beta(i)$, is a constant over time which means that M(i,t) not only measures the impact of the exploitation of new ideas on profit growth but is also equal to the impact of exploitation on nominal output growth, a measure equivalent to the growth of total factor revenue productivity (GTFRP), as explored in Foster et. al. (2008). GTFRP is a measure which confounds idiosyncratic demand and factor price effects with true efficiency differences as measured by GTFP (and, as with M(i,t), may take negative values). In Economics, GTFP is the most commonly used indicator of the impact of innovation, measuring the impact upon real output growth, and it is thus useful to draw some parallels with the measure proposed here[9]. With the profit share in revenue being constant over time, we may further write that $s(i,t) = p(i,t) + y(i,t)$, and from (2), $p(i,t) = c(i,t) + y(i,t)/\eta(i)$, and thus after substitution $y(i,t) = (s(i,t) - c(i,t))/(1 + 1/\eta(i))$. Using (13) and (14) we may then state that, in our model, M(i,t) is related to the impact of the exploitation of new ideas upon the growth of real output for firm i in time t[10], equivalent to GTFP(i,t), such that $GTFP(i,t) = M(i,t)/(1 + 1/\eta(i))$. Thus M(i,t) and GTFP(i,t) are distinct and differ from each other according to the elasticity of demand for the firm's output which is firm specific. With the data available, we have no measure of, or way of measuring $\eta(i)$, and thus we are unable to calculate GTFP(i,t).

3. Measurement and sample characteristics

3.1 Defining and measuring variables

We operationalise the derived measure of innovativeness $M(i,t) = s(i,t) – c(i,t)/\beta(i) + w(i,t)(1 – \beta(i))/\beta(i)$ for a large international sample of quoted firms using DataStream, the data in which is taken from company accounts. S(i,t) is measured by operating profits (measured by earnings before interest, taxes and depreciation, ebitda, with identifier code WC18198) with s(i,t) being its growth rate. W(i,t)H(i,t) is measured by the total of salaries, wages and benefit

[9] In fact, as a measure of the impact of innovation upon the growth in the real output of the firm (rather than upon profitability as modelled here), GTFP might itself be considered to be a measure of the successful exploitation of new ideas. We consider however that profit gain is a more widely accepted measure of firm success. In addition GTFP is often, although not exclusively, measured assuming only disembodied innovation, and often perfect competition is assumed, enabling labour and capital shares in revenue to be used as input weights. Neither are assumed here. Thus in our view the frequently cited estimates of TFP growth are not satisfactory as measures of the successful exploitation of new ideas.

[10] Although it should be noted that in most of the literature, GTFP is measured by excluding the contribution of capital growth to output growth whereas here, in a vintage model context, that is not the case.

expenses, including social security and pension costs; WC01084). Labour inputs H (in the absence of any obvious measures of labour quality) are measured by numbers employed (WC07011), we may then generate estimates of W(i,t) in thousands per person and thus w(i,t). Nominal value added, V(i,t), is calculated as operating profit S(i,t), plus employee costs, W(i,t)H(i,t), as previously defined. Labour and profit shares in value added, 1 - β(i,t) and β(i,t) respectively, follow naturally from the calculation of value added, but as the theoretical analysis assumes that β(i, t) is not changing over time (being determined by the constant parameters γ(i) and η(i), see equation (7)), we average over time the estimates of β(i,t) for each date to generate the measures of β(i) that are utilised in the calculation of M(i,t). The rate of growth of the GVA deflator in local currency for the industry and country to which the firm belongs was used to calculate c(i,t) where data was available and where not, a one price approach using US price indexes and current exchange rates was used.

There is an issue as to whether the measure of innovativeness calculated in this way is net or gross of the cost of acquiring new ideas. This will depend upon accounting conventions. Different accounting treatments of the wage and capital costs of acquiring new ideas (including R&D expenditure) and the writing off of such costs (or the capitalisation of results) could yield different estimates of total wages and salaries and operating profits, and thus different estimates of value added and factor shares and eventually our measure of innovativeness - some of which will be more net and others more gross. But in the absence of detailed information we are unable to be more precise.

3.2 The sample

As a main objective is to look at differences in innovation performance across different countries we have selected a multinational sample of firms from those present on DataStream between 1988 and 2012. From an original list of 22055 firms in 46 countries for which the data is complete we have removed firms attributed to countries with less than 500 observations (Luxembourg, Colombia, Czech Republic, Hungary, Argentina, Turkey, Mexico, New Zealand) because we want reasonable sample sizes for international comparisons. In order to allow for analysis of persistence we also exclude those firms that were suspended or died in the sample period. Not surprisingly, when active, the suspended or deceased firms registered lower values for the innovation indicator than those that remained active (which might mean there is some possibility sample selection, or survivor, bias in the results)[11].

Finally we removed extreme outliers from the sample. Extreme outliers were defined as firms in a time period that have a value for M(i, t) greater than 10 or less than -10. Without this removal M(i,t) ranges across the sample from a max of 353764.78 to a min of -67422.01. This reduces the sample by 8579 observations. The final dataset is an unbalanced sample of 16457 firms over the period 1988-2012, operating in 39 sectors and in 38 countries (yielding a total of 165970 observations)[12].

The firms in the sample may be operating domestically or be transnational but we allocate them to the country (see Table 1) to which DataStream allocates them. The UK, Germany, France and the US jointly account for about 33.4% of the sample. The sample also includes

[11] For example, the indicator of innovativeness is significantly lower for deceased (N=67321, M(i;t)= 0.01) and dead (N=3259, M(i;t)= -0.12) firms than for active firms (N=165970, M(i;t)= 0.05).

[12] Full details of the data set and all calculations are available from the corresponding author upon request.

other European countries (e.g. Italy, Switzerland, Netherlands, Spain and Sweden), Asian countries (e.g. Japan, Hong Kong, India and Malaysia), South American countries (e.g. Brazil), South Africa, and Australia.

Table 2 details the distribution of firms by sector. One may note especially that the sample includes a mix of both manufacturing and service industries. Although the firms are distributed across 39 sectors, some of those sectors have only a limited representation in the sample whereas others are very well represented. Financial services and banks, software & component services, construction and material, real estate and industrial engineering each account for 4.5% or more of the sample and jointly for a third of the sample. On the other hand less than 0.5% of the sample is in: aerospace and defence, equity and non equity investments, and life insurance.

Table 1: Distribution of observations on sample firms by country (N = 165970, i = 16404, t= 1988 – 2012)

COUNTRY	FREQUENCY	%
AUSTRALIA	6135	3.7
AUSTRIA	1215	0.7
BELGIUM	1700	1.0
BRAZIL	2179	1.3
CANADA	1538	0.9
CHILE	658	0.4
CHINA	6633	4.0
DENMARK	2387	1.4
FINLAND	1958	1.2
FRANCE	8991	5.4
GERMANY	10688	6.4
GREECE	2126	1.3
HONG KONG	12260	7.4
INDIA	9235	5.6
INDONESIA	3933	2.4
IRELAND	752	0.5
ISRAEL	1480	0.9
ITALY	3495	2.1
JAPAN	2822	1.7
MALAYSIA	6998	4.2
NETHERLANDS	2050	1.2
NORWAY	2261	1.4
PAKISTAN	1257	0.8
PERU	802	0.5
PHILIPPINES	1999	1.2
POLAND	2361	1.4
PORTUGAL	694	0.4
RUSSIAN FEDERATION	1151	0.7
SINGAPORE	4867	2.9
SOUTH AFRICA	2474	1.5
SOUTH KOREA	8047	4.8
SPAIN	2190	1.3
SRI LANKA	575	0.3
SWEDEN	4493	2.7
SWITZERLAND	3178	1.9
THAILAND	4462	2.7
UNITED KINGDOM	16648	10.0
UNITED STATES	19278	11.6
TOTAL	165970	100.0

Table 2: Distribution of observations on sample firms by sector country (N = 165970, i = 16404, t= 1988 – 2012)

SECTOR	FREQUENCY	%
Aerospace & defence	885	0.4%
Alternative energy	714	0.6%
Automobiles & parts	3570	2.0%
Banks	16443	7.8%
Beverages	1936	0.9%
Chemicals	5468	3.2%
Construct. & material	9047	5.0%
E/tronic & e/cal equipment	6124	3.9%
Electricity	2939	1.8%
Eq. and non eq. invest.	675	0.4%
Financial services	9273	6.2%
Fixed line telecom.	1406	0.7%
Food producers	6637	3.8%
Forestry & paper	1386	0.7%
Gas, water & mult. util.	1522	0.8%
General industrials	2915	1.5%
General retailers	4512	2.8%
Healthcare equipment svs.	3164	2.0%
H/hold gds & home con.	3814	2.0%
Ind. engineering	7793	4.5%
Ind. metals & mining	4229	2.7%
Industrial transport	4494	2.4%
Leisure goods	1909	1.2%
Life insurance	302	0.3%
Media	5333	3.2%
Mining	4292	3.5%
Mobile telecom.	1075	0.6%
Nonlife insurance	990	0.8%
Oil & gas producers	3178	2.2%
Oil equip. & services	1386	0.9%
Personal goods	5477	3.3%
Pharm. & biotech	4842	3.2%
REITs	1359	0.7%
Real estate inv & svs.	7814	4.7%
Software & comp. svs.	7670	5.4%
Support services	6167	3.5%
Tech h/ware & equipment	4983	3.3%
Travel & leisure	6826	3.8%
Unquoted equities	3421	3.1%
Total	165970	100.0%

As an indicator of sample characteristics, the data in Tables 3a and 3b gives the overall picture of employment in the panel. The average sample firm has 9,774 (3,118 if extremes are removed) employees. 50% of the firms have more than 745 employees while 10% have more than 15,003 employees. In general one might thus consider that the sample firms are large. In our empirical analysis we investigate whether firm size impacts upon the measure of firm innovativeness. In general we find a very low (but significant) positive correlation between innovativeness and firm size across the whole sample, which might suggest that our estimates could have an upward bias and differences in firm sizes across countries could to some degree result in inter country differences in measured innovativeness.

Table 3a. Sample employment: 1988-2012 (N= 165970)

Descriptive statistic		Measure	Std. Error
Mean		9774.03	800.32093
95% Confidence Interval for Mean	Lower Bound	8205.42	
	Upper Bound	11342.64	
5% Trimmed Mean		3118.92	
Median		754.00	
Q1		164	
Q3		3461	
Std. Deviation		36046.07	
Skewness		219.08	.006
Kurtosis		50809.55	.012

Table 3b. Sample employment: 1988-2012, percentiles (N= 165970)

Percentiles

	Percentiles						
	5	10	25	50	75	90	95
Employees	12.4607	36.0000	164.0000	754.0000	3461.0000	15003.0000	34729.6000

4. Estimates of innovativeness: The overall pattern

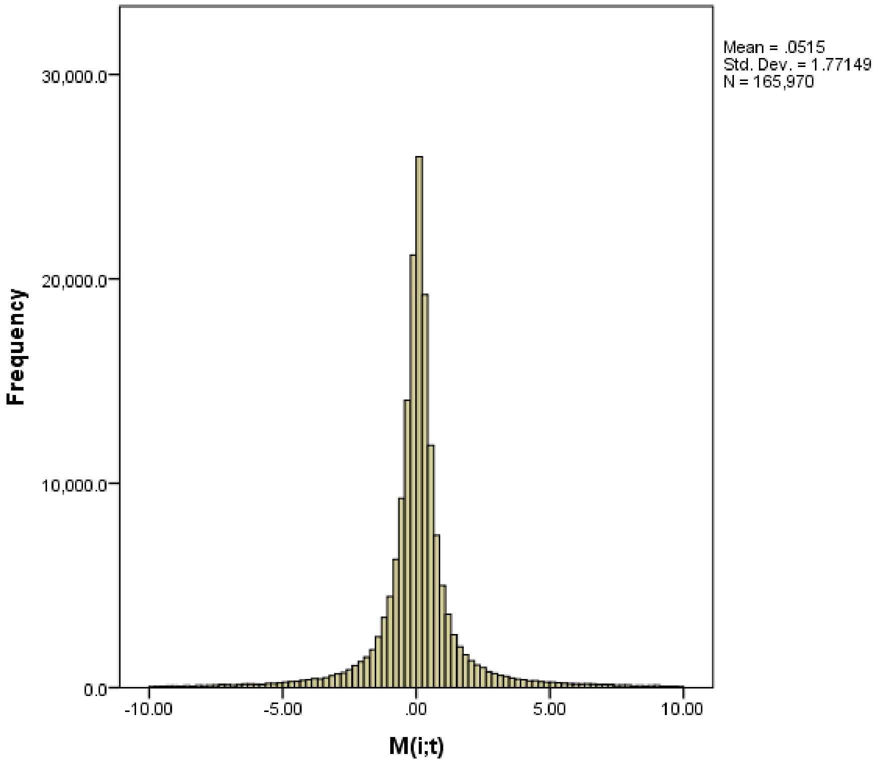
In Table 4 we present descriptive statistics on the calculated measure of the successful exploitation of new ideas, M(i,t), as defined in (15), for the whole sample for the period 1989 - 2012 (using the 1988 observations to calculate the 1989 growth rates).

Table 4: Innovativeness M(i,t): descriptive statistics (N = 165970, i = 16404, t= 1988 – 2012)

M(i,t), Descriptive statistic		Measure	Std. Error
Mean		.0515	0.00435
95% Confidence Interval for Mean	Lower Bound	.0430	
	Upper Bound	.0600	
5% Trimmed Mean		.0493	
Median		.0639	
Variance		3.138	
Std. Deviation		1.77149	
Minimum		-10.00	
Maximum		10.00	
Range		19.99	
Interquartile Range		0.91	
Skewness		0.009	0.006
Kurtosis		8.723	0.012

The data in Table 4 indicates that the mean value of the innovativeness measure over the whole panel data set i.e. the average annual rate of growth of profits that is the result of the exploitation of new ideas, is 5.15% p.a. The standard error of the mean is .00435 indicating that the mean is significantly greater than zero. The median is 6.39% per annum. However one must note that the variance is large relative to the mean and also the range is wide. The wide spread of the estimates is further shown by the histogram in Figure 1, where, although it is clear that the annual contribution is clustered around zero, with a slight positive bias, there is a wide spread of the distribution on both sides of the mean.

Figure 1: Histogram of Innovativeness M(i,t) (N = 165970, i = 16404, t = 1988 – 2012)



The innovation indicator, $M(i,t) = s(i,t) - c(i,t)/\beta(i) + w(i,t)(1 - \beta(i))/\beta(i)$, which measures the contribution of the exploitation of new ideas to the rate of growth of profits, has three parts: $s(i,t)$ the recorded growth rate of nominal profits; minus $c(i,t)/\beta(i)$ which is the extent to which measured profit growth is higher because of positive demand shifts; plus $w(i,t)(1 - \beta(i))/\beta(i)$ which is the extent to which measured profit growth is lower because of wage increases. The mean value of these three components in the sample[13] are $s(i,t) = 0.0237$; $c(i,t)/\beta(i) = 0.0242$; and $w(i,t)(1 - \beta(i))/\beta(i) = 0.052$. Thus mean $M(i,t) = 0.0237 - 0.0242 +$

[13]We discuss patterns over time below.

0.0520 = 0.0515. Thus given that s(i,t) = M(i,t) + c(i,t)/β(i) - w(i,t)(1 – β(i))/β(i) = 0.0237 = 0.0515 + 0.0242 - 0.0520, one might argue that, on average, successful innovation makes a contribution to profit growth that is almost equal but opposite in sign to the (negative) contribution of increasing wages with the realised measured profit increases being essentially equal to the contribution to profit growth from upward demand shifts.

Although there is a significant contribution from the exploitation of new ideas to firm profits, there is also wide variation across firms, countries, sectors and time. The data suggest that the largest variability can be observed over time, followed by the variability across countries, sectors and then firms. Exploring the variability further we find that: (i) the variability of the average firm innovativeness is higher within than across individual firms over time; (ii) that greater differences exist across firms (possibly driven by the growth rate nature of the measure we use) than across firm averages; and (iii) the variability in average innovativeness is higher across years than in a specific year, across sectors than within sectors, and across countries than within countries.

5. Estimates of innovativeness by country, sector, and time.

5.1 Firm level scoreboards

Our technique provides a measure of innovativeness for each of the sample firms at each point in time. There is thus the potential to rank firms (or any selection of firms) at any point of time in terms of their innovativeness and thereby create scoreboards. However, we are not primarily interested in the identity of firms that perform well or do not perform well, but we can state that the limited score boarding exercises that we have explored illustrate very little permanency in the ranking of firms over time (see also section 6 below). Our main interest instead is in the overall patterns of the innovativeness of firms across countries, sectors and time, which we explore in the next three subsections.

5.2 Inter country comparisons of innovativeness

In Table 5 descriptive statistics of the estimate of firms' innovativeness are presented by country, although it should be recalled that for data reasons some countries are excluded from this analysis and some of the country sample sizes are small. Dispersion is present not only across countries but also within countries (which observation was made long ago by Salter, 1960).

An ANOVA test indicates that the means are not the same across countries ($F = 11.067$ $p = 0.000$). However, the results are only indicative as the variability within groups is not constant (Levene's test = 49.528 $p = 0.00$) as the ANOVA test requires it to be. As an alternative we also carried out the Welch ($F_W = 846.947$ $p=0.000$) and the Brown-Forsythe ($F_{BF}=11.615$, $p=0.00$) robust tests of equality of means[14] as well as their non-parametric version based on the equality of medians ($M = 846.95$, $p = 0.000$) and on the equality in distribution of M(i,t) across countries (Kurkal-Wallis = 807.86, $p = 0.000$)**.** All tests suggest that the average innovativeness differs across countries. However, given that so few countries have mean estimates that are significantly different from the overall mean (14 out of 38) it would appear that inter country differences in innovative performance are not large for 2/3 of the countries. The data are in fact consistent with the view that intra country differences in innovative performance are greater than inter country differences. This view is supported by an analysis of variance which indicates that the variability across countries is twice the

[14] The Brown-Forsythe tests for equal population variances is a modified version of the Levene's test. Together with the Welch test of equal population means they are used when the equality of population variances cannot be assumed. Both tests are based on the F distribution but are more robust than the classical F test when the equality of variance cannot be assumed. They all suggest that mean innovativeness differs across countries.

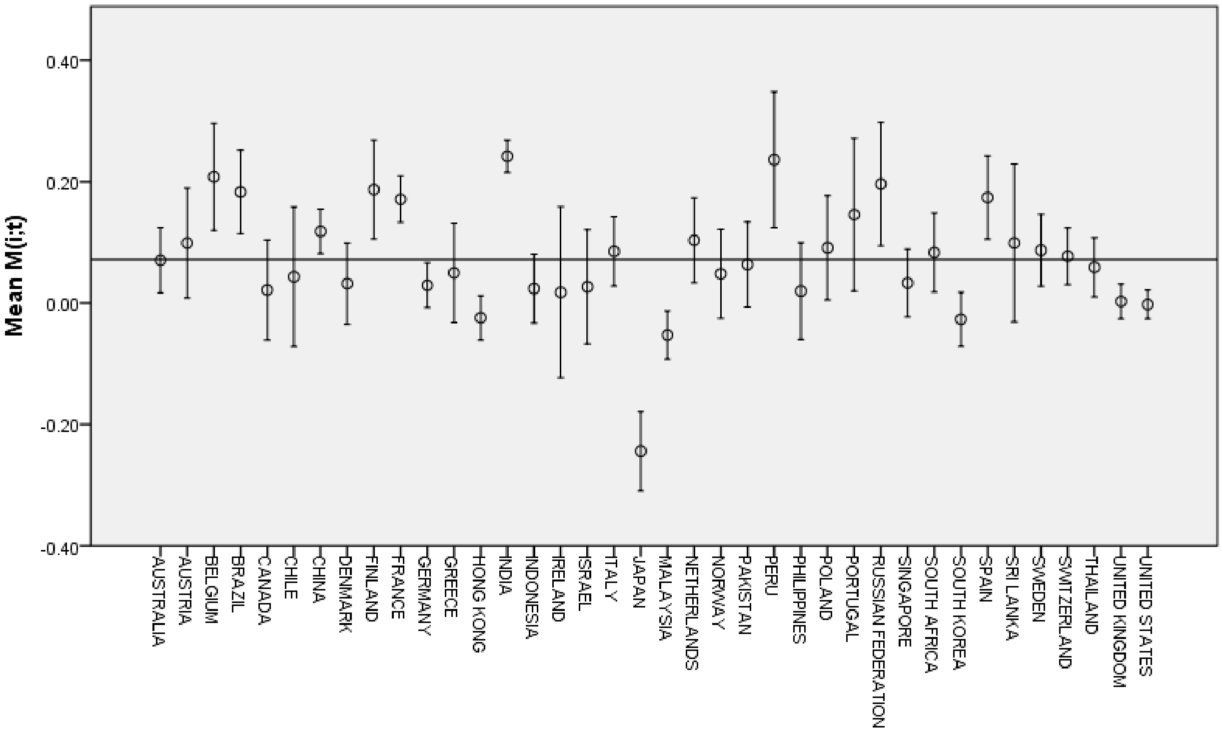
variability within countries. Such results suggest that aggregate (economy wide) indicators of innovation may have only limited value in the comparison of performance across different countries.

Table 5: Innovativeness across countries, t = 1988 – 2012

	Mean	Median	SE of Mean	St. dev	Valid N	Layer Valid N %
AUSTRALIA	.07	.06	.03	2.10	6135	3.7%
AUSTRIA	.10	.09	.05	1.58	1215	0.7%
BELGIUM	.21	.06	.04	1.82	1700	1.0%
BRAZIL	.18	.16	.03	1.61	2179	1.3%
CANADA	.02	.07	.04	1.61	1538	.9%
CHILE	.04	.05	.06	1.48	658	.4%
CHINA	.12	.15	.02	1.50	6633	4.0%
DENMARK	.03	.01	.03	1.63	2387	1.4%
FINLAND	.19	.09	.04	1.80	1958	1.2%
FRANCE	.17	.08	.02	1.80	8991	5.4%
GERMANY	.03	.03	.02	1.90	10688	6.4%
GREECE	.05	-.03	.04	1.89	2126	1.3%
HONG KONG	-.02	.04	.02	2.02	12260	7.4%
INDIA	.24	.16	.01	1.28	9235	5.6%
INDONESIA	.02	.12	.03	1.78	3933	2.4%
IRELAND	.02	.05	.07	1.93	752	0.5%
ISRAEL	.03	.01	.05	1.81	1480	0.9%
ITALY	.09	.05	.03	1.68	3495	2.1%
JAPAN	-.24	-.04	.03	1.74	2822	1.7%
MALAYSIA	-.05	.02	.02	1.67	6998	4.2%
NETHERLANDS	.10	.07	.04	1.59	2050	1.2%
NORWAY	.05	.09	.04	1.75	2261	1.4%
PAKISTAN	.06	.06	.04	1.24	1257	0.8%
PERU	.24	.14	.06	1.59	802	.5%
PHILIPPINES	.02	.05	.04	1.78	1999	1.2%
POLAND	.09	.11	.04	2.09	2361	1.4%
PORTUGAL	.15	.02	.06	1.66	694	0.4%
RUSSIAN FEDERATION	.20	.13	.05	1.73	1151	0.7%
SINGAPORE	.03	.05	.03	1.95	4867	2.9%
SOUTH AFRICA	.08	.04	.03	1.62	2474	1.5%
SOUTH KOREA	-.03	-.01	.02	2.00	8047	4.8%
SPAIN	.17	.11	.03	1.61	2190	1.3%
SRI LANKA	.10	.12	.07	1.56	575	0.3%
SWEDEN	.09	.07	.03	1.98	4493	2.7%
SWITZERLAND	.08	.06	.02	1.32	3178	1.9%
THAILAND	.06	.07	.02	1.63	4462	2.7%
UNITED KINGDOM	.003	.06	.01	1.85	16648	10.0%
UNITED STATES	-.002	.06	.01	1.65	19278	11.6%
TOTAL	.05	.06	.00	1.77	165970	100.0%

The dispersion within and across countries for the whole sample is illustrated by Figure 2 where we display the mean value of the innovation measure for each country over the period 1988-2012 and the associated confidence interval (+/- 2 standard errors of the sample mean) relative to the overall mean.

Figure 2: Innovativeness, dispersion within and across countries: means plus 95% confidence intervals (1988 - 2012)



To explore whether the firms in any one country are more or less innovative than those in other countries we observe for which countries the overall mean, 0.515, is outside the range of the country's sample mean by more (+/-) than two standard errors of that mean. From Figure 2 one may observe that on average firms in Brazil, Russia, India, China (the BRIC countries), Peru, and four EU countries (Finland, France, Belgium and Spain) are significantly above the population mean, but, on average, firms in Hong Kong, Japan, Malaysia, South Korea and interestingly, both the US and the UK, are statistically significantly below the sample mean[15]. For only two countries, Japan and Malaysia, is the mean below zero by more than two standard errors of the sample mean (i.e. significantly).

These results may not be what might have been initially expected. For example the indication that Indian firms are more innovative than firms in the US, UK and Japan might not match preconceptions[16]. It might be thought that as leaders in, for example, the development and use of new product and process technologies, that firms in the latter three countries are surely the more innovative. It has in fact been suggested to us that the result may reflect differences in firm sizes. We have explored the relationship between the measured innovativeness indicators and firm size measured by the number of employees. The linear correlation between innovativeness as measured here and the number of employees yielded a Pearson Correlation coefficient estimate of 0.007 ($p = 0.01$) indicating that larger firms are more innovative. This is quite contrary to what would be necessary to explain the measured inter country innovation pattern.

Although this paper is about what rather than why and thus we do not fully explore the determinants of innovativeness one should note at this point that the measure of innovativeness employed here is a measure of the impact of activities that are new to the firm and not new to the world. It is thus quite possible that firms in developing nations may be measured as particularly innovative because, although they may not be the most advanced, they have the potential to benefit by catching up with firms in developed economies whose

[15] One may also note that the dimension of the whiskers in Figure 2 are relatively small for countries with large sample sizes (India, China, USA, UK) and larger for countries with smaller sample sizes. This indicates that the width of the interval (i.e. the standard error of the mean) reflects not only consistency in innovativeness but also the sample size. The larger the sample the greater will be the accuracy and the lower the standard error.

[16] The results also differ considerably from those found in the European Innovation Scoreboard for 2018 (https://ec.europa.eu/docsroom/documents/32503) where using a very different methodology the most innovative countries (in the EU) are listed in order as Sweden, Denmark. Finland, the Netherlands and the UK.

production activities may already be closer to the knowledge frontier. This could be a major factor behind the finding that firms in the BRIC countries do well (as do firms in certain European nations) whereas firms in Hong Kong, Japan, Malaysia, South Korea, the US and the UK do less well.

5.3 *Innovativeness by sector*

In Table 6 the measured innovativeness of firms and related statistical indicators are tabulated by industrial sector. Using the standard error of the mean, we observe that the estimates of the sectoral means are statistically significantly above the overall mean (0.0515) for automobiles, electricity, gas water and utilities, general industrials, healthcare equipment services, industrial engineering, mobile telecoms, tech hardware and equipment, and significantly below the overall mean for banks, equity and non-equity investment, oil and gas producers, and real estate investment and services. The estimates of the sectoral means do not differ significantly from the overall mean for 27 (of the 39) sectors. Although there are thus some differences across industrial sectors, we note that there are no systematic differences between manufacturing sectors and service sectors.

Once again, the revealed pattern may not be as expected were the most innovative firms to be considered those operating at the technological frontiers or are most high-tech (gas, water and utilities, for example, are quite low tech) or spend most on R&D. Partly this may be because innovation defined here also encompasses managerial, organisational and marketing innovation, the outcome of design activities, and soft innovation, and is not limited to "technological" innovation. More relevant, however, is that the definition of innovativeness employed here is defined as relating to the first use or more extensive use of products and business processes that are new to the firm, and thus firms in catching up sectors may also be innovative.

As an informative exercise we explored correlations between our estimated measure of innovativeness and firms' R&D activity (as both a yes/no dummy variable and via the R&D/sales ratio). This exercise leads to considerable reductions in the size of the sample of firms, for many firms do not do, or do not report, R&D expenditure. Although we could see some significant positive correlation in the restricted sample between the measure proposed here and R&D activity, which one would expect, the correlation is not perfect, allowing other sources and other types of innovation to play a role in the determination of overall measured firm innovativeness. Essentially different sectors may be innovative in different ways.

Table 6: Innovativeness by sector, t = 1988 – 2012

	Mean	Median	Standard Deviation	Valid N	S.e. of mean
Aerospace & defence	.01	.04	1.63	885	.054
Alternative energy	.07	.07	2.40	714	.089
Automobiles & parts **above**	.22	.19	1.54	3570	.025
Banks **below**	.02	.08	1.19	16443	.009
Beverages	.08	.07	1.33	1936	.030
Chemicals	.07	.03	1.48	5468	.020
Construct. & material	.03	.02	1.73	9047	.018
E/tronic & e/cal Equ.	.00	.04	1.93	6124	.025
Electricity **above**	.12	.08	1.51	2939	.028
Eq. and noneq. invest. **below**	-.23	-.10	2.14	675	.082
Financial services	.02	.04	2.01	9273	.020
Fixed line telecom.	.12	.10	1.54	1406	.041
Food producers	.05	.06	1.56	6637	.019
Forestry & paper	-.02	-.03	1.91	1386	.051
Gas, water & mult. util **above**	.15	.10	1.26	1522	.032
General industrials **above**	.12	.06	1.51	2915	.028
General retailers	.09	.11	1.68	4512	.025
Healthcare equip. svs. **above**	.12	.09	1.84	3164	.032
Hholds & Home con.	.02	.05	1.72	3814	.028
Ind. engineering **above**	.10	.12	1.68	7793	.019
Ind. metals & mining	.08	.04	1.69	4229	.026
Industrial transport	.09	.07	1.41	4494	.021
Leisure goods	.04	.03	1.87	1909	.042
Life insurance	.04	.12	1.74	302	.100
Media	.01	.04	2.01	5333	.027
Mining	.03	-.01	2.15	4292	.032
Mobile telecom. **above**	.19	.13	1.61	1075	.049
Nonlife insurance	-.01	.11	1.74	990	.056
Oil & gas producers **below**	-.04	-.04	1.94	3178	.034
Oil equip. & services	.11	.12	1.58	1386	.042
Personal goods	.02	.07	1.81	5477	.024
Pharm. & biotech	.05	.05	1.68	4842	.024
REITs	.05	.06	1.63	1359	.044
Real estate inv & svs **below**	.00	.03	1.93	7814	.022
Software & comp. svs.	.08	.11	2.35	7670	.026
Support services	.03	.05	2.00	6167	.025
Tech hware & equipmnt. **above**	.17	.19	2.12	4983	.030
Travel & leisure	.02	.04	1.84	6826	.022
Unquoted equities	.02	.03	1.78	3421	.030
Total	.05	.06	1.77	165970	.044

5.4 Innovativeness over time

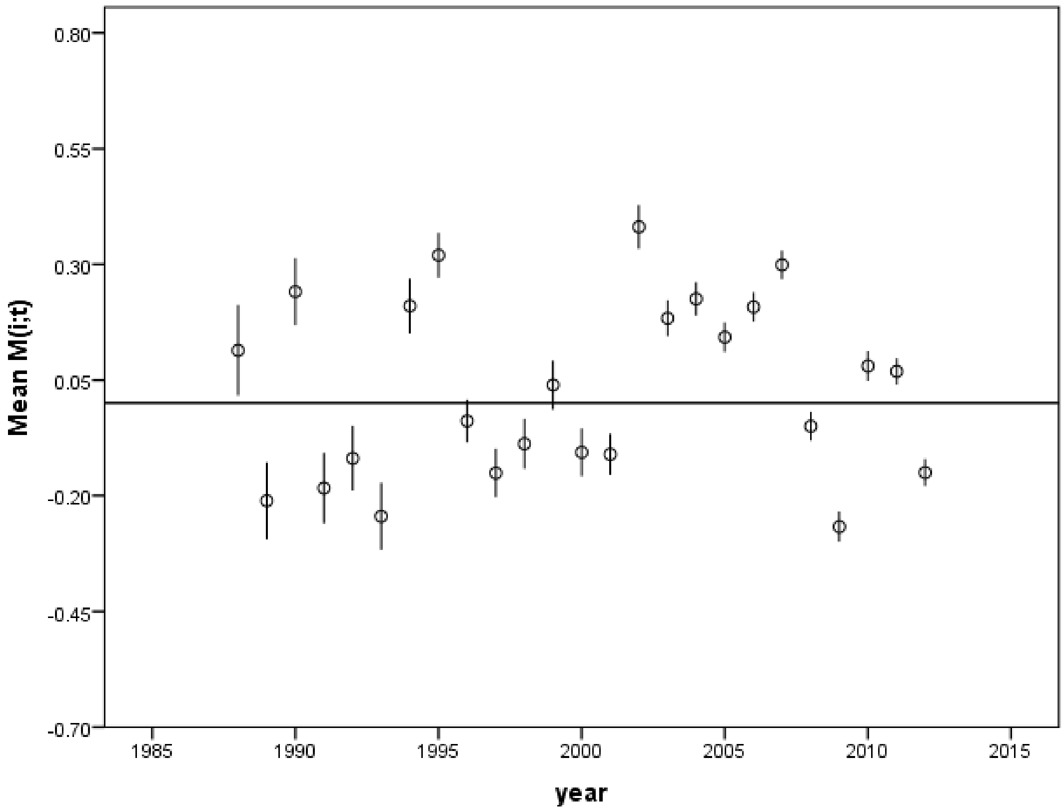
Table 7 presents estimates of the average value of the innovativeness index over the whole sample of firms for each year between 1988 and 2012 with other associated statistical indicators. Figure 3 plots for each year the estimate of the mean for that year, whiskers indicating plus and minus two standard errors of the mean for each year, and a horizontal line at zero. The distribution of innovative performance across firms is not invariant with respect to time. The mean estimates show a wide spread with the highest measured mean being 0.38 in 2002 and the lowest being -0.27 in 2009. From Figure 3 we may observe that the estimate of mean innovativeness is statistically greater than zero for 12 years and significantly below for 11 years. It does not differ from zero in two years. One may also note that, for every year, whether the sign of the mean is positive or negative, the maximum value for a firm in that year is always positive and the minimum is always negative, so, at every date, some firms are getting a positive contribution to profits from innovative activity even if others are not[17]. Figure 3 also illustrates that there were significant reductions in mean innovativeness 1988/9, 1990/91, 1995/6, 1996/7, 1999/2000, 2002/3, 2004/5, 2007/8, 2008/9 and 2011/12 with significant increases 1989/90, 1993/4, 1998/9, 2001/2, 2005/6, 2006/7, and 2009/10. Of the 24 measured annual changes in means, 7 do not differ significantly from zero. The pattern does not reveal any upward or downward trend in the means over the sample period.

[17] Data available from the corresponding author.

Table 7: Innovativeness over time, t = 1988 – 2012.

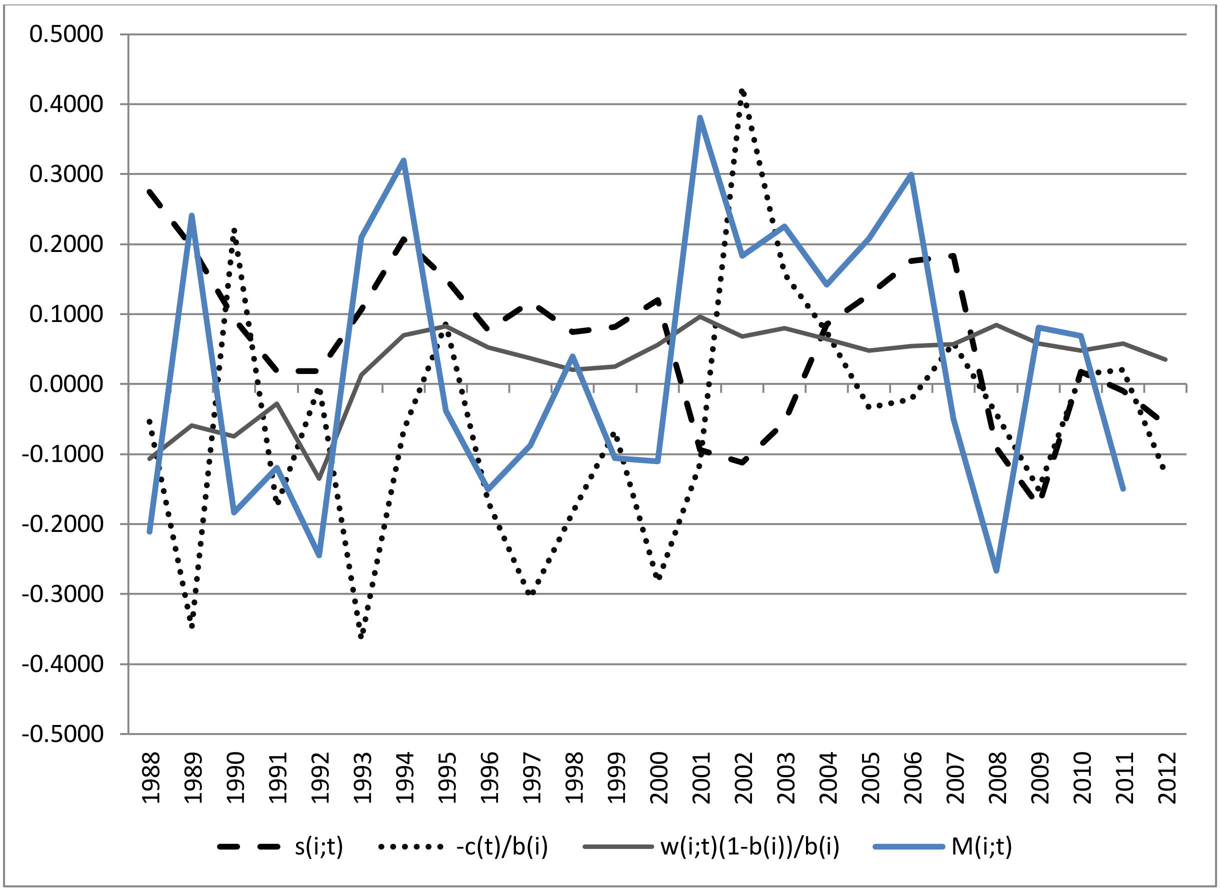
Year	Mean	Median	Standard Error of Mean	Valid N
1988	.11	.11	.05	934
1989	-.21	-.16	.04	1182
1990	.24	.24	.04	1381
1991	-.18	-.12	.04	1497
1992	-.12	.00	.04	1788
1993	-.24	-.15	.04	1989
1994	.21	.15	.03	2275
1995	.32	.23	.02	2611
1996	-.04	-.02	.02	2946
1997	-.15	-.15	.03	3484
1998	-.09	.02	.03	3945
1999	.04	.07	.03	4316
2000	-.11	-.06	.03	5010
2001	-.11	-.10	.02	6596
2002	.38	.16	.02	7814
2003	.18	.17	.02	8553
2004	.23	.20	.02	9342
2005	.14	.11	.02	10184
2006	.21	.16	.02	11432
2007	.30	.24	.02	12280
2008	-.05	-.01	.02	12842
2009	-.27	-.19	.02	13393
2010	.08	.14	.02	13587
2011	.07	.10	.01	13932
2012	-.15	-.08	.02	12657

Figure 3: Innovativeness, p.a. dispersion from the mean (95% confidence intervals) t= 1988 – 2012



Just as we decomposed the separate contributions of measured profits, s(i,t), demand shifts, – c(i,t)/β(i), and wage growth, w(i,t)(1 – β(i))/β(i) to M(i,t) for the whole of the sample period above, we may also decompose movements in M(i,t) over time into movements in these three constituent parts. In Figure 4 we plot annual averages for s(i,t), – c(i,t)/β(i), w(i,t)(1 – β(i))/β(i)) and M(i,t). Eyeballing this data would suggest that over time w(i,t)(1 – β(i))/β(i) has switched from negative to positive and is becoming less volatile. This implies that in later years it is changes in measured profit growth and the growth resulting from demand shifts that have been the major driving factors behind changes in M(i, t). These two components show only limited correlation over time, in some periods their contributions reinforce each other in other periods they counteract each other.

Figure 4. The three components of M(i ;t): annual averages



6. Multivariate analysis and persistence

The analysis above is essentially univariate, looking at patterns across time, country or sector individually. In this section we undertake a multivariate analysis by regressing M(i,t) against a series of dummy variables representing, country, sector and time, looking for significant (at 5%) differences. In pursuing this exercise we also explore persistence in firm performance by including a one period lagged performance term as a regressor, a positive coefficient for which will indicate whether, having taking account of country, sector and time, firms with higher measured innovativeness in time t -1 also reveal higher performance in time t.

Taking the lag structure into account the initial sample involves 143,140 observations. Although the R^2 is only 0.0170, the F statistic is highly significant. For the sake of space we do not present the results in detail[18] but on the key issues we find as follows.

(i) There is a positive significant coefficient on one year lagged innovativeness of 0.032, p= 0.00) indicating that there is some evidence of positive persistence.

(ii) Largely in line with the univariate analysis above, the coefficient estimates of the country dummies indicate that firms in Brazil, Russia, and India (but, perhaps surprisingly, not China) Peru and four EU countries (Finland France, Belgium, and Spain) show rates of innovation that are significantly (p = 0.05) higher than in other countries while firms in Hong Kong, Japan, Malaysia, S. Korea and interestingly, both the US and the UK, show measured rates on innovativeness that are significantly lower.

(iii) There are significant differences between sectors in measured innovative performance. The estimated coefficients on the sector dummies indicate that the sectors estimated to have measured performance significantly lower than in other sectors include (lowest performers first) equity and non equity investment, oil and gas producers, mining, personal goods, forestry and paper, electronic and electrical equipment, pharmaceuticals and bio tech, real estate and support

[18] These are available from the corresponding author upon request.

services. This is a mix of high tech, low tech, manufacturing and services as observed in the univariate analysis.

(iv) The estimated coefficients on the time dummies for 1990, 1994, 1995, 1999, 2002, 2003, 2004, 2005, 2006 2007, 2009 2010 and 2011 are significantly ($p=0.05$) greater than zero (that for 2002 being largest) but for all other years the coefficients do not differ significantly from zero. This closely matches the pattern shown in Figure 3.

Overall therefore we might conclude that the multivariate analysis largely supports the findings from the univariate analysis. One extra insight it offers, however, is that there appears to be some positive persistence in innovativeness.

7. Causality

In this section we explore revealed patterns of causality between M(i,t), s(i,t), c(i,t) and w(i,t). Although the paper is largely about what rather than why, there are, in principle, many ways in which the firm's innovativeness may feed back upon demand shifts, wage growth and the growth in operating profits, and thus it is useful to check whether: (i) as modelled, M(i,t) is 'caused' by s(i,t), c(i,t) and w(i,t) as theorised, for if an indicator is to be a measure of performance then it must reflect the output from a performance generating process and not be a measure of input to that process; (ii) that, as assumed, c(i,t) and w(i,t) are exogenous to the firm and thus not caused by M(i,t); and (iii) that s(i,t) is not caused by M(i,t) because if it were then we would not estimating a true reduced form and our estimates of M(i,t) may be biased.

We assess causality (i.e. output vs. input) in the Granger sense. The Granger causality test states that X is a Granger cause of Z if Z can be predicted with better accuracy by including in the information set the past values of X rather than by not doing so (other information being identical). Although there are many critiques of the Granger approach to causality we think the exercise is indicative, if not definitive, and in any case other approaches we have explored have yielded similar results to those reported here. We specify the following testing equation:

(16) $Z(i,t) = \Gamma \mathbf{\Omega(i,t)} + \Sigma_{j=1} \gamma_j \mathbf{Z(i,t\text{-}j)} + \Sigma_{k=1} \lambda_{\mathbf{k}} \mathbf{X(i,t\text{-}k)} + \varepsilon(i,t)$ i = 1…N, t = 1988,…….2012

where $\Omega(i,t)$ denotes the deterministic (non-stochastic) variables of the equation, i.e. intercept, time trend, sector dummies, country dummies, etc., Γ is a vector of parameters and $\varepsilon(i,t)$ is a vector of error terms. A Granger causality test is carried out over the joint significance of the λ_k's. The hypothesis of non-causality $\Sigma_{k=1}\lambda_k=0$ (i.e. X does not cause Z) can be tested using the Lagrange Multiplier Statistics in its F-form (LMF)[19]. If the null (Ho : $\Sigma_{?f} \lambda_k = 0$) cannot be rejected then one can conclude that 'X does not cause Z' . If the null cannot be retained then the observed changes in Z are caused by past changes in the X, i.e. X causes Z. Furthermore, the joint significance of the past realizations of the dependent variable Z (Ho: $\Sigma_{j=1} \gamma_j = 0$) will allow testing the hypothesis of no path dependency while the analysis of the sign of the γ's will indicate the extent of persistency.

Because our modelling process defines the measure of the successful exploitation of new ideas as M(i,t) = s(i,t) – c(i,t)/β(i) + (1 – β(i))/β(i), the most obvious approach, given that β(i)

19 The LMF instead of having the usual χ^2 distribution with k degrees of freedom, has asymptotic F distribution with degrees of freedom equal to the number of restrictions imposed (k) and the difference between the sample size and the number of parameters in the unrestricted model (T-h).

is constant across firms, is to test whether our performance innovation measure is caused by, or causal to the growth rate of operating profits s(i,t), demand shifts, c(i,t) and wage growth employment w(i,t). In order not to limit ourselves to unilateral analysis we also carry out multidimensional analysis whereby each variable is also specified as a function of the other variables (including its own lag). The estimation process is repeated for each of the four variables under scrutiny, M(i,t), s(i,t), c(i,t) and w(i,t).

Our preferred specification is obtained when lag 3 is used. The results of the dynamic multivariate regression are reported in Table 8. All specifications include a full set of time, sector and country dummies. The first block of results tests whether the innovation measure M(i,t) is path dependent, and hence affected by its past realisations and also whether its current value is affected by current and/or past realizations of s(i,t), c(i,t) and w(i,t), the growth rate of profits, industry demand shifts and the growth rate of wages respectively.

The results are reported in the first three columns of Table 8[20] showing that the null is rejected in all three cases, suggesting that s(i,t), c(i,t) and w(i,t) are all causal to the innovation measure. This is exactly as one would require from a performance measure. The last three columns of Table 8 test whether our innovation performance measure is causal to the innovation exploitation process, i.e. whether s(i,t), c(i,t) and w(i,t) are caused by current and/or past realizations of M(i,t). The results show that the null is retained in the case of s(i,t) and w(i,t) indicating that they are not caused by current and/or past realizations of our innovation measure. However, there is some evidence of reverse causality, with c(i,t) ($t = 10.24$, $p = 0.000$). This might suggest that the innovativeness of firms can shift the demand curve that they face. Our estimates above do not allow for this. The first row of Table 8 also

[20] Full details of the estimates are available from the corresponding author upon request.

confirms our earlier finding that our innovation measure is path dependent (t = 6.03, p = 0. 05) i.e. that high innovativeness today is "caused" by high innovativeness in the past.

Table 8: Causality testing, whole sample

M(i,t) is caused by X			M(i,t) is causal to X		
M(i,t) =f(X)	F	**P>|t|**	**X = f(M(i,t))**	F	**P>|t|**
Path dependency of M(i,t) Ho: $\Sigma\gamma_{M(i,t)}=0$	6.03	0.05	-	-	-
s(it) causes M(i,t) Ho: $\Sigma\ \beta_{s(i,t)}=0$	22.44	0.000	M(i,t) causes s(i,t) Ho: $\Sigma\beta_{M(i,t)}=0$	0.27	0.848
c(i,t) causes M(i,t) Ho: $\Sigma\ \beta_{c(i,t)}=0$	10.43	0.000	M(i,t) causes c(i,t) Ho: $\Sigma\beta_{M(i,t)}=0$	10.24	0.000
w(i,t) causes M(i,t) Ho: $\Sigma\ \beta_{\omega(i,t)}=0$	2.83	0.037	M(i,t) causes w(i,t) Ho: $\Sigma\beta_{M(i,t)}=0$	0.89	0.44

Note: All specifications include the full set of time, sector and country dummies; The F statistic has 3 degrees of freedom (equal to the number of restrictions imposed), and the difference between the sample size and the number of parameters in the unrestricted model, given the lag structure, is 105438.

8. Conclusions

In this paper we have defined, constructed and calculated an output orientated measure of the innovativeness of firms using an encompassing indicator that reflects the firm's successful exploitation of new ideas. In essence the measure indicates the rate of growth of a firm's nominal profits arising from increased embodied and disembodied utilisation of new ideas. It is calculated as a residual equal to the difference between the growth in the nominal profits of the firm and the impact upon that growth of an appropriately weighted sum of changes in exogenously determined wage rates and inflation/demand shifts in the market for the firm's output. Particular advantages to the measure are that it is equally relevant to service firms as manufacturing firms when alternative indicators such as R&D spending or patent counts may not be so, and it allows for all the several different types of innovation that firms may undertake, including soft innovation, managerial, organisational and marketing innovation. The measure offers transparency and simplicity of calculation and requires only data that is widely available in the public domain, thereby generating a large sample of firms, both nationally and internationally, for study. Such properties are desirable for any scoreboard type measure of this kind (Arundel, 2001, lists other desirable criteria for related score boarding exercises).

Using data upon an unbalanced sample of 16457 firms over the period 1988-2012, operating in 39 sectors and in 38 countries (yielding a total of 165970 observations) we have calculated the measure of innovativeness for each firm for each time period as data allowed. The mean value of the innovativeness measure over the whole panel data set i.e. the average annual rate of growth of profits that is the result of exploitation of new ideas, is 5.15% p.a. with a median of 6.39% per annum. A particularly stark result is the wide variance in the measured innovativeness of firms, both at a point in time and within individual countries and sectors. We find that differences within sectors, or countries, or at a point in time are greater than differences across sectors, countries or time.

The main findings (from univariate analysis largely confirmed by multivariate analysis) are that: (i) the mean innovativeness for firms in Brazil, Russia, India, China, Peru, and four EU countries (Finland, France, Belgium and Spain) is statistically significantly above the population mean whereas for firms in Hong Kong, Japan, Malaysia, South Korea, the US and the UK mean innovativeness is significantly below the population mean, a result we suggest that may partly reflect that innovation, as defined, may encompass catching up; (ii) there are some significant differences across industrial sectors but these do not reflect either the high tech nature of sectors or whether the sector is in manufacturing or services; (iv) mean innovativeness varies significantly over time; and (v) there is some evidence of persistence in firm innovativeness. An exploration of Granger causality largely confirms (apart from some unmodelled feedback from innovativeness to shifts in demand) that the estimates of innovativeness have validity as indicators of output from the innovation process, although some further exploration of the complexity of transmission over time of the impact of innovation on wages, prices and outputs may well be desirable.

In total, the exercise performed here is innovative in operationalising a measure of innovation (the successful exploitation of new ideas) that although used previously in policy discussion and analysis was rather vague. In doing so we have formally explored the relationship between innovation and firm performance and derived an indicator of firm level innovativeness that is encompassing, and enables the exploration of statistically significant differences in firm innovativeness across countries, sectors and time. This represents an important advance on both existing firm level and macro level innovation measurement exercises.

Of course the methods employed here do have limitations. The use of residual techniques has a number of problems which have been detailed in past literature. In addition the data employed here is for quoted firms and this means that non-quoted, probably smaller firms, do not figure in the analysis. For similar reasons the approach does not take account of newly established firms. These latter problems however represent the limitations of the data available rather than any criticism of the approach per se.

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